2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #33458

Social, Technical... and Environmental?: Addressing Environmental Entanglements as a Part of Engineering Education

Dr. Elizabeth A. Reddy, Colorado School of Mines

Elizabeth Reddy is an Assistant Professor in the Department of Engineering, Design and Society at Colorado School of Mines. She is a social scientist, holding a PhD in cultural anthropology from the University of California at Irvine.

Dr. Shannon Davies Mancus, Colorado School of Mines

Work in Progress

Social, Technical… and Environmental?: Addressing Environmental Entanglements as Part of Engineering Education

Abstract

Training students to be sensitive to the entanglements of technologies and social life has been an important move for engineering educators interested in advancing generative critiques of engineering, connecting to student values, and framing new perspectives about what engineering can be. However, scholarship in Science and Technology Studies (STS) and Environmental Humanities makes the case that engineering is more than sociotechnical. Environmental conditions, forces, and agents are critical to consider in relation to technologies, too.

In this paper, we suggest that introducing students to engineering as a social, technical, and environmental activity has productive implications. Here, we outline two main areas of pertinent theory. We group these areas into systems theories and material vibrancy and enchantment theories. For each of these, we 1) offer a synopsis of the insights, key texts, and implications and 2) show the utility of the approach to advance important pedagogical goals specifically related to socially responsible engineering practices in engineering education.

Introduction

Engineering educators often seek to train students to see engineering as sociotechnical. By this, we mean that we want them to be sensitive to how technologies and social factors intertwine; considering how engineering has effects on society as well as how engineering activities are social themselves, informed by the social and cultural structures in which they occur. This work is valuable and necessary. However, approaching engineering as a sociotechnical activity can still center human choices, actions, and effects. Such an anthropocentric approach to the world may neglect perspectives developing in academic fields and popular culture. Educators and students alike ask: if engineering is sociotechnical, what about animals that engineers and their stakeholders love, the bugs that eat up their wires, the storms that destroy their photo voltaic cells, the hazards that inspire them to action, or all that their traditional homelands mean to them? These perspectives direct our critical attention to the relationships between humans, technologies, and the many nonhuman beings, forces, and systems which surround and suffuse them, allowing us to address such questions explicitly within our pedagogy.

When we teach, we seek to advance generative critiques of engineering, connect to student values, and frame new perspectives about what engineering can be. This is not a minor project, as the work of a wide community of scholars in engineering education can attest (see, for example, [1] [2] [3]). We find that recent scholarship in Environmental Humanities and Science and Technology Studies (STS) offers conceptual tools to help us develop such curricula. This scholarship develops paradigms for addressing what we sometimes call “non-humans” in relation to technologies and social life— paradigms that offer insights that sociotechnical perspectives alone may not and that conventional treatments of human-environment relations that we find in work on sustainability neglect. For our students at Colorado School of Mines, many of whom love the outdoors and see the forces of climate change shaping their daily lives and long-term technical ambitions, these perspectives can inform how we craft lessons in order to make concepts related to social and environmental justice more immediate and directly meaningful.

In the fields of STS and Environmental Humanities, approaches that often go by the names of "post constructivism" and "new materialism" provide some generative ways of acknowledging and engaging with our broadening understanding of social, technical, and environmental enmeshment [4]. Research and writing that uses these approaches is not just a matter of attending to so-called "context," but instead seeks to pull the places, materials, and creatures around us and within us out of the periphery of our attention and into the center of action and analysis. While this move may seem at first glance to be about everything but humans, it actually allows us to focus on issues of justice and equity within human communities, giving us new ways to understand how we harm and marginalize each other as well as how we are related to each other. Indeed, many of these perspectives focus on non-humans in order to help us better understand what environments mean to us, to seriously engage with non- Eurocentric ways of thinking, or to really grapple with the material effects that environmental contamination can have for communities who live in environmental sacrifice zones. Using these concepts in the classroom can pull students into deep conversations about ethics and responsibility and emphasize the need for more far-reaching visions of technical communication and community engagement, like those explored in recent work on Socially Responsible Engineering [[5]].

In this paper, we focus particularly on what we call systems theories and material vibrancy and enchantment theories. For each of these, we offer a synopsis of several key insights, texts, and implications. Then, we show the utility of the approach in question to advance important pedagogical goals related to ethics and critical humanitarian practice in engineering education. We show how we are using these theories in the classroom now and describe why.

While deep dives into these topics and implications may be more appropriate for some classrooms than others, we contend that even considering engineering's anthropocentrism and the potential for non-human agency can be—and indeed, has been—productive for lesson planning. For those professors that have more time and space in their syllabi, more explicit engagement with topics can frame provocative experiences that students respond to. Regardless, considering the theoretical orientations which inform our pedagogies facilitates thoughtful modes of critical participation within engineering projects [6]. We also seek to contribute to developing nuanced intellectual tools appropriate to a trend of ASEE scholarship identified by Neeley *et al.* in which engineering educators engage STS for projects related to "embedded sociotechnical systems thinking" undertaken by educators and scholars with diverse training [7].We hope that our work in this paper will help us and other educators and scholars articulate goals for our classrooms and identify thoughtful strategies to achieve them.

Many engineering educators may already be engaged in working through concepts that we outline here, but they may not often reflect explicitly on how it includes and exceeds the scope of what we might understand as "sociotechnical engineering". With this in mind, this paper is not so much a critique of engineering education as a consideration of a movement already underway and encouragement to keep building on it. It is a work in progress inasmuch as we note sociotechnical engineering's scope in engineering education, as well as what environmental perspectives add and their utility, require more extensive research.

More than sociotechnical and not just sustainable

Recent scholarship in STS and Environmental Humanities makes the case that environmental conditions, forces, and agents are critical to consider in relation to technologies (see, for example, [8] [9] [10]). These scholars offer a small but meaningful shift in perspective, a turn away from attention to the choices that humans can make as the be-all and end-all of engineering and an opportunity to undermine high modernist, technosolutionist ideas about simplified systems that can be totally controlled by rational engineers (many examples of critiques of this work exist, but a particularly poignant one can be found in [11]). As historian Sara Pritchard puts it, social, technical, and environmental are mutually interdependent fields of knowledge and action, though acknowledging them as such means grappling with "complicated, dialectical dynamics among all three factors simultaneously" [12]. This perspective troubles the notion that good engineering depends only on an individual engineer's calculative skills and that the success of technology can be assessed by its function, instead asserting the importance of considering the contribution to and effects of technology within a complex world. As such, above all else, these theoretical bodies of work offer support for the development of epistemic humility (demonstrated in work such as [13][14]). If we hope to help engineering students build capacities to be respectful, responsive, and responsible within their own communities and those that may be somehow impacted by their choices, than this is a very useful proposition indeed.

One way that some educators teach students to include different actors and effects in their engineering work is by pairing their sociotechnical approaches to engineering with attention to sustainability. Sustainability allows them to address a technology's ongoing impact by interrogating its production and use in terms of good long-term outcomes. Many approaches to sustainability use a "triple bottom line" to address the importance of thinking about the effects of a technology for "people, planet, and profit"—that is, for humans, for non-humans, and for the economic interests of investors. For all its utility, the concept of sustainability remains extremely elastic in engineering contexts [15]. While it may have powerful potential, "sustainability" can also simply indicate a priority for maintaining current levels of comfort with small environmentally friendly changes to our lives or to stretch out our limited supplies of natural resources.

Some educators and scholars, including Leydens and Lucena [16], write about teaching sustainable development in relation to macro-ethics or social justice. In their classes, sustainability can be a means of challenging status quos, teaching humility, and showcasing responsible practice. However, this is not explicit in the concept. In fact, Andrade and Tomblin note that from their perspective, "environmental dimensions of sustainability easily fit into an engineering program" while issues like macro-ethics are more challenging to integrate [17]. If sustainability fits so easily within mainstream approaches to engineering, than its utility to challenge students to rethink engineering might depend more on instructor interests than the material itself. Sustainability asks us to think about long-term impacts, but does necessarily trouble our ideas about authorship or our models for “good outcomes”.

Some might well argue that if our orientations toward sustainability drive engineering students to consider broad environmental consequences that may impact stakeholders’ health and economic wellbeing in any way, this is a success. We agree that meeting ABET criteria by teaching students new ways to understand engineering and its effects and new skills for reflecting upon and enacting their values is a tremendous and important undertaking, however it is achieved [18].We contend, however, that explicitly drawing on contemporary research on systems theories and material vibrancies and enchantment theories can offer essential tools for engineering educators who seek to push their students further. They support ideas about inextricable connections between humans and non-humans, and, doing so, facilitate incredibly valuable conversations about what engineering is, what it does, and for whom.

Systems theories can let us teach students about relationships with and effects of non-humans

Thinking about systems can help us understand how one central human actor or technical product is informed by many relations and connections to other people, conditions, forces, and creatures. Systems theories are often used to help students understand the complex conditions of their engineering work [19] [20] [21], as well as to describe engineering education itself [22] [23] [24] [25]. Systems theories, as a bare minimum, open up conversations about connection and relation. They can incorporate more than social and technical elements that are the product of human life and human design work. As such, they have tremendous potential to decenter human agency when they challenge us to interrogate what should be considered part of a given system and how it might influence and be influenced by other system elements.

Systems theories used today in engineering often owe a great deal to cybernetics, developed in the mid 20th century as a mode for addressing how complex systems regulate themselves and can be designed so that they produce desirable effects in the process [26] [27] [28]. This mode of approaching systems was developed as interdisciplinary from the start and, in a move that is particularly relevant for us here, “removed the human and Homo sapiens from any particularly privileged position in relation to matters of meaning, information, and cognition” [29]. Though it has generally come to refer to virtual or computer- related activities, Norbert Wiener, who first coined the term cybernetics [30], simply used it to refer to systems governance. It offered then, and still offers today, a powerful set of tools for thinking through interaction, influence, and order—which made it a way of describing ecological interaction as well as machine action. In the words of anthropologist Gregory Bateson, who brought cybernetic theory to bear on his work: "The basic rule of systems theory is that, if you want to understand some phenomenon or appearance, you must consider that phenomenon within the context of all completed circuits which are relevant to it" [31].

While cybernetic theories may be directly related to our students’ work in computer science and robotics, other systems theories are also consequential for them. Actor Network Theory (ANT), for example, is another way of considering non-human and human elements in systems as active and agential (see, for example, [32] [33] [34]).Where cybernetics is a good way to consider how outcomes of complex systems can be controlled, ANT is better applied to interrogating what might make any outcome under consideration possible. Critics note that ANT may not be the most productive tool for nuanced analysis related to, for example, social power and inequities [35] or the different levels of skill that humans (or non-humans) can bring to their endeavors [36]. Nonetheless, considering the network of actors involved in an undertaking can help us better understand relationships and effects [37].

Table 1. System Theories in Brief

Qualities of System Theories	**Useful Texts**	**Classroom Activities**	**Topics Supported**
• Emphasize connection and relation between diverse elements of a system • A technology is informed by, and has consequences for, many different people, conditions, forces, and creatures.	G. Bateson. *A Sacred Unity: Further Steps to an Ecology of Mind*. San Francisco: Harper. 1991 B. Latour. 2005. *Reassembling the Social: an Introduction to Actor-Network-Theory*. Oxford: Oxford University Press J. Law, "Technology, closure, and heterogeneous engineering: The case of Portuguese expansion". In W. Bijker, T. Hughes, & T. Pinch (Eds.), *The social construction of technical systems: New directions in the sociology and history of technology* Cambridge, MA: MIT Press, J. 1987, pp. 111–118.	• Students brainstorm and draw out elements of a system that impact/are impacted by a technology • Students discuss how changing an apparently-minor element of a system might change an outcome.	• Unintended consequences of engineering • Values in engineering practices • Environmentally and socially responsible engineering

The authors have, in different classes and in relation to different projects, asked students to simply list or diagram networks of actors related to topics of interest. These activities have rarely been framed with little explicit reference to specific systems theories; instead, the authors have offered these activities as brainstorming or implosion exercises [38]. The systems or networks that students draw out can incorporate humans, nonhumans, individuals, organizations, forces, spaces, and more on a single chart.

Similarly, other engineering educators have found asking students who and what is involved in an engineering problem is found to help students appreciate the social responsibility of engineers for unintended consequences of their choices [39] [40]. As Rosalyn Berne writes, for her, teaching with ANT meant that ethics "emerged in the course, not solely as maximizing benefits, prescriptions for following rules, or adhering to codes and principles, but also as narrative negotiations between and among a variety of actors, some of who have conflicting interests" [41]. This system theory challenged students to ask what was truly involved in the technologies under analysis, and interrogate their components and relations rather than simply considering "public good". This kind of careful parsing is what systems theories have to offer us as educators.

Material vibrancy and enchantment theories let us provoke students to consider what humans and non-humans are

Unlike system theories, it is not the complexity of networks that approaches to environments and non-human actors that what we call material vibrancies and enchantment theories serve to foreground. Instead, acknowledging vibrancy often means focusing on only one material, creature, or place and its specific significance. This kind of attention works like a microscope to reveal the complexity and significance of something that might seem simple or distinct, and undermine our ideas about what comprises the "one" person, force, thing, or being under investigation [42] [43] [44] [45]. Enchantment, on the other hand, focuses on humans' perceptions of the so-called "natural" world (which can be more diverse than we assume, see [46]. and encourages the disruption of Euro-centric common sense that, for example, perceives as "nature" as inert and separate from humanity and devalues meaningful relationships with land [47] [48]. While sociotechnical approaches to engineering might help us ask how society and technology inform each other, these theories prompt questions about what exactly a given place or item *is*, both physically and conceptually, and whether our assumptions about cause and effect, nature, and identity are really true to our experiences or to the experiences of others.

Work on this can sensitize us to the wide range of encounters with and reactions to environments that matter to engineers and the people they work with and for. Stacy Alaimo, for example, reminds us that "the human is always inter-meshed with the more-than-human world," and that this "underlines the extent to which the substance of the human is ultimately inseparable from 'the environment'" [49]. This is more than a nice turn of phrase. What Alaimo calls "intermeshing" is a reminder of what our environments mean to us and the tangible situations in which what we may think of as clear distinctions between "human" and "environment" break down. Examples include toxins that can have severe health effects that are especially experienced by marginalized and under-resourced populations. Tracing the traffic in toxins may be environmental, but it involves understanding environments and people as more than a matter of the "welfare of wild creatures" [50] (see also [51]).

While some scholars push us to question whether common-sense distinctions we may assume exist between different actors in our networks are actually meaningful, other thinkers make us consider the roles that non-humans really play in our lives and choices. This work can ontologically reorient students while rendering environments and objects as intellectually captivating and persuasive. When Jane Bennet defines vitality as "the capacity of things... to act as quasi agents or forces with trajectories, propensities, or tendencies of their own" she reminds us that our way of conceiving of the world around us is socially constructed and many of the things we build our assumptions of the world upon could very well be understood otherwise [52].

Table 2. Material Vibrancy and Enchantment Theories in Brief

Qualities of Material Vibrancy and Enchantment Theories	**Useful Texts**	**Classroom activities**	**Topics Supported**
• Emphasize the complexity and significance of something that might seem simple or distinct • Undermine assumptions about what comprises the "one" person, force, thing, or being under investigation.	M. Mendéz. *Climate Change From the Streets*. New Haven: Yale University Press, 2020. S. Alaimo. *Bodily Natures: Science, Environment, and the Material Self.* Bloomington: Indiana University Press, 2010 J. Price Thirteen ways of Seeing Nature in LA: Part I," *Believer Magazine*, Apr. 01, 2006.	• Discuss paradox of development related to Roman Empire • Identify and describe different ways of seeing nature in students' daily life	• Values in engineering practices • Environmentally and socially responsible engineering • Engineering identities, inclusions, and exclusions • Environmental injustices and environmental justice movements

Engaging with these themes in the classroom means helping students think about the impact that environments can have on people and their choices. In doing so, it also troubles narratives of human mastery over "nature". This disruption can have an effect on students' perception of professional ethics (for example, an expanded understanding of the precautionary principle) and understanding of seemingly intractable societal problems (such as disparities in environmental health).

One approach used by the authors involves exploring material vibrancy in a series of lectures and discussions in our freshman ethics and composition class, Nature and Human Values. First, in order to emphasize that engineering decisions can advance human society but can also have unexpected consequences, students are asked to ruminate on the paradox of development. Students are exposed to debates about whether or not the lead that may have leached into the drinking water of Roman elites from their fancy lead-lined plumbing system may have contributed to the fall of the Roman Empire by altering the neurological states of its most influential citizenry (although some recent scholarship challenges this narrative) [53]. While acknowledging this situation as a potential engineering failure, we also gesture toward the idea that substances can act upon humans in unexpected ways, up to and including their behavior and cognition. In later modules, students are asked to contemplate how confluences of social and material factors impact modern society, including in relation to environmental justice, using texts including [54] [55]. This reconceptualization aims to help students rethink what they engineer with and upon.

Discussion and conclusion

In this paper we have discussed scholarship in STS and Environmental Humanities, exploring some implications for engineering education. We have focused on explicitly non-anthropocentric perspectives, considering two modes of approaching such work which we have called systems theories and material vibrancy and enchantment theories. The literature review of diverse, beautiful, and intriguing work that we provide here is far too brief. We hope, however, it facilitates an introduction for those unfamiliar with the material and provokes consideration of this work’s implications for engineering education.

Including environment—that is, animals, materials, forces, places, and more—in our approaches to engineering is slightly different from considering engineering as a sociotechnical activity. It adds elements to our understanding of how technology is developed and how it works. However, doing so does not mean neglecting engineers and the communities that inform technologies and experience their positive and negative impacts. Rather, these perspectives suggest ways of thinking about engineering that can challenge our students to be more reflective and attend to responsible practice in new ways. More research on sociotechnical engineering in engineering education, as well as what the kinds of environmental perspectives we outline here may add, require more research which we hope to undertake in concert with other interested scholars and educators.

References

[1] S. Secules, A. Gupta, A. Elby, C. Turpen. "Zooming out from the struggling individual student: An account of the cultural construction of engineering ability in an undergraduate programming class." *Journal of Engineering Education* vol. 107 no. 1, pp. 56-86, 2018.

[2] J. A Mejia and M. N. de Paula "'Ingeniero como vos': An analysis of the Mbyá-Guaraní Practices Associated with Engineering Design" Paper presented at 2019 ASEE Annual Conference & Exposition, Tampa, Florida, 2019.

[3] E. A. Cech. "Culture of Disengagement in Engineering Education." *Science, Technology & Human Values*, vol. 39, no. 1, pp. 42-72, 2013.

[4] H. Knox, and T. Huse. "Political Materials : Rethinking Environment , Remaking Theory." *Distinktion: Scandinavian Journal of Social Theory* vol. 16, no. 1, pp. 1–16, 2015. https://doi.org/10.1080/1600910X.2015.1028419.

[5] J. M. Smith and J. C. Lucena. "Socially Responsible Engineering" in D. P. Michelfelder and N. Doorn (Eds) *The Routledge Handbook of the Philosophy of Engineering*. New York: Routledge, 2021, pp 661-673.

[6] G. L. Downey. "What Is Engineering Studies for? Dominant Practices and Scalable Scholarship." *Engineering Studies* vol. 1, no. 1, pp. 55–76, 2009. https://doi.org/10.1080/19378620902786499.

[7] K. A. Neeley, C. D. Wylie, and B. Seabrook. "In Search of Integration : Mapping Conceptual Efforts to Apply STS to Engineering Education," presented at 2019 ASEE Annual Conference & Exposition , Tampa, Florida. pp. 11, 2019.

[8] S. B. Pritchard, Confluence: *The Nature of Technology and the Remaking of the Rhone.* Cambridge, MA: Harvard University Press, 2011.

[9] N. Starosielski, *The Undersea Network*. Durham, NC: Duke University Press, 2015.

[10] A. Carse, *Beyond the Big Ditch: Politics, Ecology, and Infrastructure at the Panama Canal.* Cambridge, MA: MIT Press, 2014.

[11] T. Mitchell, *Rule of Experts: Egypt, Techno-Politics, Modernity*. University of California Press, 2002.

[12] S. B. Pritchard," Toward an Environmental History of Technology" in A. C. Isenberg, Ed., *Oxford Handbook of Environmental History*. Oxford: Oxford University Press, 2014, pp. 231

[13] V. Despret,. "The becomings of subjectivity in animal worlds." *Subjectivity* vol. 23, no. 1, pp. 123-139 2008.

[14]V. Despret “Domesticating practices.” G. Marvin and S. McHugh, eds. *Routledge handbook of Human-Animal Studies*. London, UK: Routledge, 2014

[15] G. Miller. “Exploring Engineering and Sustainability: Concepts, Practices, Politics, and Consequences.” *Engineering Studies* vol. 6, no. 1 pp. 23–43, 2014. https://doi.org/10.1080/19378629.2014.902951.

[16] J. A. Leydens, and J. C. Lucena. “Social Justice: A Missing, Unelaborated Dimension in Humanitarian Engineering and Learning Through Service.” *International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship* vol. 9, no. 2 pp. 1–28, 2014. http://library.queensu.ca/ojs/index.php/ijsle/article/view/5447%5Cnhttp://queens.scholarsportal.info/ojs/index.php/ijsle/article/view/5447

[17] N. A. Andrade, and D. Tomblin. “Engineering and Sustainability: The Challenge of Integrating Social and Ethical Issues into a Technical Course.” Paper presented at 2018 ASEE Annual Conference & Exposition, Salt Lake City, UT. 2018.

[18] ABET, Accreditation Criteria 2020-2021 https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2020-2021/

[19] G.E. Ermer. “The Complexities of Engineering Design and System Modeling Paper” Presented at 2012 ASEE Annual Conference & Exposition, San Antonio, Texas. 2012.

[20] J. Y. Tsai, and D. A. Kotys-Schwartz, and D. Knight. “Introducing Actor–Network Theory via the Engineering Sophomore Year Paper” presented at 2015 ASEE Annual Conference & Exposition, Seattle, Washington. 2015.

[21] R. W. Berne. “In-vitro Fertilization (IVF) as a Sociotechnical System: Using Actor-network Theory (ANT) for Teaching Undergraduate Engineers About the Ethics of Assisted Reproductive Technology (ART)” Paper presented at 2018 ASEE Annual Conference & Exposition, Salt Lake City, Utah. 2018.

[22] J. Juhl and H. Lindegaard. "Representations and Visual Synthesis in Engineering Design." *Journal of Engineering Education* vol. 102, no. 1, pp. 20–50, 2013. DOI 10.1002/jee.20001

[23] L. Vanasupa, and L. T. Schlemer. “Relational versus Transactional Community Engagement: An Experience of the Benefits and Costs.” Paper presented at 2014 ASEE Annual Conference & Exposition, Indianapolis, Indiana. 2014.

[24] L. Vanasupa and C. J. Thurman. “Transdisciplinarity for Sustainability: A Unifying Framework for Navigating Transformational Learning Systems.” Paper presented at 2018 ASEE Annual Conference & Exposition , Salt Lake City, UT. 2018.

[25] K. McConnell. “Mapping & Strengthening Curriculum-Based Industry/Academia

---

Intersections." Paper presented at 2019 ASEE Annual Conference & Exposition, Tampa, FL, 2019.

[26] J. Walker and M. Cooper. "Genealogies of Resilience From Systems Ecology to the Political Economy of Crisis Adaptation*." Security Dialogue* vol. 42, no. 2, pp. 143–60, 2011. https://doi.org/10.1177/0967010611399616.

[27] A. Pickering, *The Cybernetic Brain Sketches of Another Future*. University of Chicago Press, Chicago, 2010.

[28] E. Medina, *Cybernetic Revolutionaries: Technology and Politics in Allende's Chile*. Cambridge: MIT Press, 2011.

[29] C. Wolfe. *What is Post Humanism*. Minneapolis: University of Minnesota Press. 2009, p. xiii.

[30] N. Wiener. *Cybernetics; or, Control and Communication in the Animal and the Machine*. New York: J. Wiley, 1948.

[31] G. Bateson. *A Sacred Unity: Further Steps to an Ecology of Mind*. San Francisco: Harper. 1991, p. 260

[32] B. Latour. 2005. *Reassembling the Social: an Introduction to Actor-Network-Theory*. Oxford: Oxford University Press

[33] M. Callon, "Some Elements of a Sociology of Translation: Domestication of the Scallops and the Fishermen of St. Brieuc Bay," in *Power, Action and Belief: a New Sociology of Knowledge?*, J. Law, Ed. London: Routledge, 1986.

[34] J. Law, "Technology, closure, and heterogeneous engineering: The case of Portuguese expansion". In W. Bijker, T. Hughes, & T. Pinch (Eds.), *The social construction of technical systems: New directions in the sociology and history of technology* Cambridge, MA: MIT Press, J. 1987, pp. 111–118.

[35] K. Fortun. "From Latour to Late Industrialism." *Hau: Journal of Ethnographic Theory* vol. 4, no. 1, pp. 309–329, 2014.

[36] T. Ingold. *Being Alive.* New York: Routledge, 2011.

[37] B. Williams-Jones and J. Graham, "Actor-Network Theory: a tool to support ethical analysis of commercial genetic testing," *New Genetics and Society*, vol 22 no. 3, pp. 271- 296, 2010. DOI: 10.1080/1463677032000147225

[38] E. Reddy, B. Przestrzelski, S. M. Lord, and I. Khalil. "Introducing Social Relevance and Global Context into the Introduction to Heat Transfer Course." Paper presented at 2018 ASEE

Annual Conference & Exposition , Salt Lake City, UT, 2018.

[39] G. Rulifson, C.J McClelland, and L. A. Battalora, "Project-based Learning as a Vehicle for Social Responsibility and Social Justice in Engineering Education." Paper presented at 2018 ASEE Annual Conference & Exposition , Salt Lake City, Utah, 2018.

[40] D. Nieusma, and J. W. Malazita, "'Making' a Bridge: Critical Making as Synthesized Engineering/Humanistic Inquiry." Paper presented at 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana, 2016.

[41] R. W. Berne, "In-vitro Fertilization (IVF) as a Sociotechnical System: Using Actor-network Theory (ANT) for Teaching Undergraduate Engineers About the Ethics of Assisted Reproductive Technology (ART)." Paper presented at 2018 ASEE Annual Conference & Exposition , Salt Lake City, Utah, 2018, pp. 11

[42] D. Coole and S. Frost, eds. *New Materialisms: Ontology, Agency, and Politics*. Durham: Duke University Press, 2010.

[43] D. Haraway, "Anthropocene, Capitalocene, Plantationocene, Chthulucene: Making Kin." *Environmental Humanities* vol. 6, no. 1, pp. 159–65, 2015. https://doi.org/10.1215/22011919-3615934.

[44] E. A. Povinelli. *Geontologies: A Requiem to Late Liberalism*. Durham: Duke University Press, 2016.

[45] P. Harvey, E. C. Casella, G. Evans, H. Knox, C. McLean, E. B. Silva, N. Thoburn, and K.Woodward, eds. *Objects and Materials: A Routledge Companion*. Routledge, 2014

[46] J. Price, "Thirteen ways of Seeing Nature in LA: Part I," *Believer Magazine*, Apr. 01, 2006. https://believermag.com/thirteen-ways-of-seeing-nature-in-la/

[47] J. Sundberg." Decolonizing Posthumanist Geographies*." Cultural Geographies* vol. 21 no. 1, pp. 33–47, 2013.

[48] J. L. Rosiek, J. Snyder, and S. L. Pratt. "The New Materialisms and Indigenous Theories of Non-Human Agency: Making the Case for Respectful Anti Colonial Engagement." *Qualitative Inquiry* vol. 26, no. 3–4, 2020.

[49] S. Alaimo. *Bodily Natures: Science, Environment, and the Material Self*. Bloomington: Indiana University Press, 2010, pp. 2.

[50] S. Alaimo, and S. J. Hekman. *Material Feminisms.* Bloomington: Indiana University Press, 2008, pp. 9.

[51] M. Mendéz. *Climate Change From the Streets.* New Haven: Yale University Press, 2020.

---

[52] J. Lorimer. "Nonhuman Charisma." *Environment and Planning D: Society and Space* vol. 25, 2007.

[53] S. C. Gilfillan "Lead Poisoning and the Fall of Rome", *Journal of Occupational Medicine* vol 7, no. 2, pp 53-60, 1965.

[54] D. Cusick. “Past Racist "Redlining" Practices Increased Climate Burden on Minority Neighborhoods,” *Scientific American*. January 21, 2020. https://www.scientificamerican.com/article/past-racist-redlining-practices-increased-climate-burden-on-minority-neighborhoods/ (accessed Mar. 06, 2021)

[55] K. Bagley “Connecting the Dots Between Environmental Injustice and the Coronavirus,” *Yale E360.* May 7, 2020. https://e360.yale.edu/features/connecting-the-dots-between-environmental-injustice-and-the-coronavirus (accessed Mar. 07, 2021).